Innovative Remote Smart Home for Immersive Engagement

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1. Introduction

Lab classes are undoubtedly essential in order to provide suitable training of future engineers. Although these lab classes have been traditionally carried out in a physical lab environment, the current evolution of communication and computing resources allow for remote control of experiments. This project is a remote lab which will be available to educators via the web. This remote lab can be used in the instruction of topics such as heat transfer, energy efficiency, HVAC, thermodynamics and power management. Users will be able to get real time data from the experimental setups (water heating and window blinds) and a live stream of the scaled smart home.

In general, the online laboratories can be categorized as either remote or virtual [1]. The virtual laboratory is based on software such as LabVIEW, Java Applet, Flash, Matlab/Simulink or other software to simulate the lab environment [2]. A remote lab is a mix of both physical and virtual aspects [3]. The principal aim of a remote lab is to represent the partial or full state of an experiment, at the client side, and to enable real-time interaction. As the experiment physically takes place and the data generated is from actual measurements it provides fundamentally the same or approximately the same experience as hand-on analyses in the laboratory in certain situations. Although simulations require no physical experimental hardware and thus require no setup time, the lack of physically interacting with equipment limits some students. Although given sufficient computing resources are available, students have the flexibility to run single or often multiple simulations at any time thereby exploring the potential outcomes by varying experimental parameters.

The last two decades, virtual laboratories have helped to teach students and train technicians in a broad range of engineering areas. For example, Abouhila et al. [4] presented a mechanism to control alternating and direct current voltage equipment through an Arduino board connected to the internet via an Ethernet shield. This work highlights the implementation of a remote experience using low cost equipment. Tian et al. [5] proposed an idea of remote lab and presented a conceptual design of the system which can be accessed by mobile phone. Alves et al. [6] in their paper discussed how remote labs would let students do more experiments with electrical and electronic circuits in a sustainable way. A MOOC-ready online FPGA laboratory platform which targets computer system experiments has been proposed by Zhang et al. [7] to help students run experiments with real hardware online and debug the hardware logic design issues. Garc'ia-Orellana et al. [8] presented a remote laboratory experiment of analog electronics based in RedPitaya which has a dual-core ARM processor and is able to run a version of the Linux operating system. The setup also includes a high-performance FPGA to allow for more demanding digital signal processing to be performed. Carpeño et al. [9] used a remote laboratory (eLab3D) in order to provide broader practical skills training in electronics. eLab3D is a resource that facilitate students' acquisition of practical skills in the field of electronics, focusing on the key competences related to each phase of the development cycle of an electronic circuit.

Samuelson et al. presented a report on the migration process of a remote laboratory setup based on remote panels in LabVIEW to an HTML5-based webpage [10]. The use of open free software enables the system to be implemented on various hardware platforms including small and inexpensive devices such as Arduino and Raspberry Pi. It was mentioned that the effort of developing the software for a remote lab may be marginally higher when using an open, free, and general platform than a proprietary platform like LabVIEW. The use of remote labs in many other areas of science and engineering has increased over the last years. Including electrical engineering [11], analog electronics [12], robotics [13][14], automation and control engineering [15] and physics [16]. However, in these and many other approaches found in the literature, the designed solutions to develop remote labs can be considered specific [17][18][19]. Each of them solves in its own way the different aspects implicated in the remote lab development [20]. In a general way, the remote access to lab classes can be divided in three strongly interconnected systems and present in this kind of training activities are learning management, experimental and communication systems.

Although not a new concept, very few actual deployed remote laboratories exist or are planned including Massachusetts Institute of Technology (MIT) iLabs [21] and Vlab [22]. The MIT lab hosts an electrical engineering lab online which is shared across many universities. The Vlab currently under development targets to have lab environment for every engineering course. This is a joint venture among major Indian universities including the India Institute of Technology and Indian Institute of Information Technology campuses. The University of Technology Sydney remote laboratory uses real, physical equipment with a live video feed. [23] The VISIR (Virtual Instrument Systems in Reality) is a project by Blekinge Institute of Technology (BTH), Sweden together with National Instruments in USA and Axiom EduTech in Sweden [24] which is an electronic circuitry lab with a virtual breadboard and relay switching matrix combination.

Some examples of simulation-based remote include Virtlab which is a series of simulated experiments and demonstrations for a course in chemistry. [26] OLAB is a distributed VLSI lab that connects all BITS campuses (Pilani, Goa, Dubai and Hyderabad) with an industrial center at Bangalore. [27] Howard Hughes Medical Institute (HHMI) [have produced fully interactive biomedical laboratory simulations that include a bacterial identification lab, a cardiology lab, a neurophysiology lab and a virtual ELISA (Enzyme-Linked Immunosorbent Assay), using human antibodies to diagnose disease. [28] The Virtual Labs Project in Stanford began in 1998 with funding from HHMI. [29] Finally, the Johns Hopkins University virtual laboratory/science course offers simulation-oriented problems without the overhead incurred in maintaining a full laboratory. [30]

In the 2nd International Conference of the Portuguese Society for engineering education 2016 about Spreading remote lab usage paper [31]. This paper aims at describing the features of a remote lab named Virtual Instruments System in Reality, embedded in a community of practice and forming the spearhead of a federation of remote labs. More particularly, it discusses the advantages and disadvantages of remote labs over virtual labs as regards to scalability constraints and development and maintenance costs. Finally, it describes an actual implementation in an international community of practice of engineering schools forming the embryo of a first world-

wide federation of Virtual Instruments System in Reality nodes, under the framework of a project funded by the Erasmus+ Program. In the 10th International Conference on Remote Engineering and Virtual Instrumentation (REV) 2014 paper on Graphic Technologies for Virtual, Remote and Hybrid laboratories: WebLab-FPGA hybrid lab the authors talk about hybrid lab where instead of the lab environment having sets of LED's they are using a virtual model or world [32]. Advanced graphics requirements suggested WebGL due to its hardware acceleration capabilities. However, mobility requirements suggested Canvas, as its support of mobile browsers is currently wider. Three.js is a quite popular JavaScript library which supports both Canvas and WebGL rendering. In this case, WebGL is used by default but the system fallbacks to Canvas if it is not supported. Hybrid lab can be one of the research topics for future remote labs. The journal paper on Empirical Analysis of the Use of the VISIR Remote Lab in Teaching Analog Electronics talks about the increasing use of remote lab in classroom which are now substituting the hands-on laboratories [33]. This paper approaches it more quantitative than qualitative analysis. The VISIR remote laboratory's positive effect on students' learning processes indicates that remote laboratories can produce a positive effect in students' learning if an appropriate activity is used.

2. Booking Application

The methodology used for the project is as shown in Figure 1. The booking application is an external application, but it controls the access to the experimental setup.

Figure 1: Five steps to access the experimental setup.

Through the booking app the users first register with the system with their name, organization and contact information. After registration the user can choose from available booking slot(s) and select from one to eight slots in which they want to run their experiment. Each slot is a 30-minute period of access to the experimental setup. The booking application allows only the specified user to access the booked slots which in turn control access the remote lab. The smart house is loaded into the booking application dashboard. A user can never access the experimental setup or any component of it directly without booking a time slot. PHP7-based opensource framework Laravel was used to develop the booking application. For the front-end JavaScript libraries such as Vue.js, jQuery and Bootstrap for CSS styling were used. In short, the booking application plays the role of a gatekeeper to allow only one user to access the experimental setup on a given timeframe. Figure 2, shows dashboard of the booking app for a user after logging into the booking app.

Figure 2: Logged in user dashboard on booking application

3. Experimental Setup

The experiment setup is a remote lab that consists of a miniature smart home (Figure 3), water heater and blinds (Figure 4) designed for remote use. Water heater and blinds are included in the remote lab to give users knowledge about heat transfer and heat sustainability as this equipment is used in general households. Figure 7 shows the real wattage used by general home appliances if the switches are turned on. It also shows combined wattage used as Total Wattage. As shown in Figure 4, we have used pleated fabric and standard vinyl blinds to compare their differences on heat transfer. The same comparison is done between insulated and uninsulated water heaters, shown in Figure 4. On the webpage, the real time temperature data of the sensors in the water heaters and behind the blinds is shown. In summary, all the experiments help the educators teach their students how to use energy efficiently. Section 4 explains the educational activities that can be carried out using the remote lab and more educational resources are available online on the BEEAM website (<http://beeam.niu.edu>).

Hardware Setup: In this remote lab we have water heaters, blinds and small-scale home appliances with LED indicators attached to them. Two Raspberry Pis are used: one Raspberry Pi controls the smart house, and the other is used to control the heaters and blinds setup. The first Raspberry Pi is used to control the LEDs connected to the miniaturized home appliances placed in the smart house using an eight-channel relay, and the sensors used in the sealed room to calculate the apparent temperature of the room. The second Raspberry Pi is used to control an eight-channel relay and sensors for the heater and window blind experiments. Raspberry Pi 3 B+ microcomputers which have 1.4GHz 64-bit quad-core processors are used for the experiment setup. An Adafruit DHT22 temperature and humidity sensor along with a Modern Device wind sensor were used to characterize a sealed room within the smart home (Figure 3). The sealed room also includes a thermoelectric cooling unit and a separate fan to investigate the behavior (e.g. apparent temperature) of using an air conditioning unit versus using a ceiling fan within a typical home setting. Four Adafruit MAX31856 temperature sensors with K-type thermocouples are used for measuring the temperature of the water in the water heater experiment and behind the blinds (See Figure 4). Two Adafruit eTape sensors are used to measure the water level of the

container in order to provide low water level alerts. Each water container is heated using a 500-watt submersible water heater. Table 1, shows list of hardware used.

Hardware Used	Number	Model
Temperature and Humidity Sensor	1	Adafruit DHT-22
Wind Sensor	1	Modern device
Thermocouple	4	Adafruit MAX31856
Water Level Sensor	1	Adafruit 12 inches eTape sensor
Eight Channel Relay	2	
Immersible Water Heater	2	500 Watt

Table 1: Hardware

Software Setup: As mentioned above in section 2 that after booking a slot via Booking app a user can access these setups remotely. On web it shows the pages to use the experiment and control the appliances. A Python script runs on each Raspberry Pi to collect the sensor data and store into a SQLite database table every five seconds. A Python-based micro web framework called Flask was used in both Raspberry Pis in order to run the server on each. While Flask worked as a server, to show real time data jQuery was used in order to use JSON served by the Flask. A script for Flask contains the coding to control smart home LEDs via POST method. Bootstrap was used for CSS styling and vanilla JavaScript was used for displaying the wattage required to run the various appliances within the home.

Figure 3: Smart home

Figure 4: Water heater and blind experiment

In this project user can control the smart home appliances which have LEDs attached to them as an indicator and can check the wattage of each appliances and the total wattage utilized by each appliance which are turned on. Figure 4 shows the screenshot of the smart house webpage. In the

second setup the students can control insulated and non-insulated water heater to investigate concept around heat transfer and energy efficiency (Figure 4). The third setup which is based around window blinds, students can control the heat source (heat lamp) placed in front of the blinds and determine the blinds effective heat transfer for both a standard vinyl and pleated fabric blind (Figure 4). The block diagram for the connection of different sensors with Raspberry Pi is shown in the Figure 5 and 6.

Figure 5: Connection layout of sensors with Raspberry Pi.

Figure 6: Connection layout of sensors with Raspberry Pi for heater and blind setup.

Figure 7: Webpage calculator using real-time data as well as live video feed.

Figure 8: Webpage interface for the water heater experiment.

Figure 9: Webpage Interface for the window blinds experiment.

4. Educational Activities

Three activities can be carried out using Innovative Remote Smart Home for Immersive Engagement: 1) Operating Smart House to understand the concepts of energy efficiency and power management 2) Water Heater experiment setup 3) Blind experiment setup

- 1) **Operating Smart House:** Students will have eight buttons to operate the house appliances and can see the real time data for temperature, humidity and wind speed for the sealed room displayed on the webpage as shown in Figure 6. The webpage as shown in Figure 6 has a live feed of the scaled model of the smart house. LED's are attached to the home appliances as an indicator for ON/OFF the appliances. Users/Students should be able to find the apparent temperature for the given parameters of wind speed, temperature and humidity. From this experiment it can be inferred that energy can be saved by just using the fan which utilizes less energy than the air conditioner, as there is not much difference in the ambient temperature when we use either of them as seen in the experiment data.
- 2) **Water Heater Experiment:** Users are advised to operate the insulated and non-insulated water heater for specific time (3-4 mins) and observe the temperature readings of the water in the water heaters. This can be used by the instructors to teach students/users about heat transfer and energy efficiency. The webpage for the experiment is shown in figure 8.
- 3) **Blind Experiment Setup:** Users can operate the heat lamp placed in front of the blinds, observe the temperature readings behind the blind and understand the difference between the material and temperature behind the blinds. This experiment can be used by the instructor to teach students/users about the heat transfer and energy efficiency. The webpage for the experiment is shown in figure 9.

Educational resources are also available on the website which could be used by the instructors for teaching about energy consumption, efficiency and how to save energy on day to day basis.

5. Conclusion

The Innovative Remote Smart Home for Immersive Engagement is a resource that help students to get practical knowledge in the fields like heat transfer, energy efficiency, power consumption and power management. It is a useful and versatile platform that can be used at different educational levels. It is particularly suitable for improving the efficiency of online education programs, facilitating the student's learning anywhere and anytime.

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